ABA-Based Answer Set Justification

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Motivation

- **Answer Set Programming (ASP)** used for complex problem solving in many domains
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- sanctions a set of literals justified ("true")
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- idea: use **argumentation theory**
  - ⇒ Assumption-Based Argumentation (ABA)
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- idea: use **argumentation theory**
  ⇒ Assumption-Based Argumentation (ABA)
- more specifically: **stable extension** semantics for argumentation frameworks
  ⇒ common roots with stable model semantics
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- **Answer Set Programming** (ASP) used for complex problem solving in many domains
- sanctions a set of literals justified ("true")
- problem: no explanation why literals are (not) in an answer set
- particularly important for real-world applications
- idea: use argumentation theory
  \( \Rightarrow \) Assumption-Based Argumentation (ABA)
- more specifically: **stable extension** semantics for argumentation frameworks
  \( \Rightarrow \) common roots with stable model semantics
- Note: only **consistent extended logic programs** (no constraints, disjunction, ...)
Answer Sets

\[ \mathcal{P}_{\text{fly}}: \]

\begin{align*}
\text{fly} & \leftarrow \text{bird}, \neg \text{abnormalBird} \\
\text{abnormalBird} & \leftarrow \text{bird}, \text{wounded} \\
\neg \text{fly} & \leftarrow \text{wounded} \\
\text{wounded} & \leftarrow \\
\text{bird} & \leftarrow
\end{align*}
Answer Sets

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\text{wounded} & \leftarrow \\
\text{bird} & \leftarrow
\end{align*}
\]

answer set: \{\text{bird, wounded, } \neg \text{fly, abnormalBird}\}
Argumentation Theory

Argumentation Framework:

- **L**: formal language
- **R**: set of rules
- **A**: set of assumptions
- **¯**: \( A \rightarrow L \) contrary relation for assumptions
- **arguments**: deductions from assumptions and rules
- **attacks**: conclusion of assumption used in another argument

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Argumentation Theory

Argumentation Framework:

- set of arguments
Argumentation Theory

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- set of arguments
- attacks between arguments
Argumentation Theory

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- semantics: “acceptable” set of arguments, based on attacks
Argumentation Theory

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Assumption-Based Argumentation (ABA) framework $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \bar{\cdot} \rangle$

$L$: formal language
$\mathcal{R}$: set of rules
$\mathcal{A} \subseteq \mathcal{L}$: set of assumptions
$\bar{\cdot}: \mathcal{A} \rightarrow \mathcal{L}$: contrary relation for assumptions
arguments: deductions from assumptions and rules
attacks: conclusion of $A$ is contrary of assumption used in $B$
Argumentation Theory

Argumentation Framework:
- set of arguments
- attacks between arguments
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Assumption-Based Argumentation (ABA) framework $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \overline{\mathcal{A}} \rangle$
- $\mathcal{L}$: formal language
Argumentation Theory

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**Assumption-Based Argumentation (ABA) framework** $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \bar{\cdot} \rangle$

- $\mathcal{L}$: formal language
- $\mathcal{R}$: set of rules
Introduction

Argumentation Theory

**Argumentation Framework:**
- set of arguments
- attacks between arguments
- semantics: “acceptable” set of arguments, based on attacks

**Assumption-Based Argumentation (ABA) framework** \(<\mathcal{L}, \mathcal{R}, \mathcal{A},\neg>\)
- \(\mathcal{L}\): formal language
- \(\mathcal{R}\): set of **rules**
- \(\mathcal{A} \subseteq \mathcal{L}\): set of **assumptions**
Argumentation Framework:
- set of arguments
- attacks between arguments
- semantics: “acceptable” set of arguments, based on attacks

Assumption-Based Argumentation (ABA) framework \(\langle \mathcal{L}, \mathcal{R}, A, \neg \rangle\)

- \(\mathcal{L}\): formal language
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- \(A \subseteq \mathcal{L}\): set of assumptions
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Argumentation Theory

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**Assumption-Based Argumentation (ABA) framework** $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \neg \rangle$
- $\mathcal{L}$: formal language
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- **arguments**: deductions from assumptions and rules
Argumentation Theory

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Assumption-Based Argumentation (ABA) framework \( \langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \neg \rangle \)
- \( \mathcal{L} \): formal language
- \( \mathcal{R} \): set of rules
- \( \mathcal{A} \subseteq \mathcal{L} \): set of assumptions
- \( \neg : \mathcal{A} \to \mathcal{L} \): contrary relation for assumptions

- arguments: deductions from assumptions and rules
- attacks: conclusion of \( A \) is contrary of assumption used in \( B \)
Translated ABA framework

\[ P_{\text{fly}}: \]
- \( \text{fly} \leftarrow \text{bird, not abnormalBird} \)
- \( \text{abnormalBird} \leftarrow \text{bird, wounded} \)
- \( \neg \text{fly} \leftarrow \text{wounded} \)
- \( \text{wounded} \leftarrow \)
- \( \text{bird} \leftarrow \)
Translated ABA framework

\[ P_{fly}: \]
- \( fly \leftarrow bird, not\ abnormalBird \)
- \( abnormalBird \leftarrow bird, wounded \)
- \( \neg fly \leftarrow wounded \)
- \( wounded \leftarrow \)
- \( bird \leftarrow \)

Translated ABA framework \( \langle L, R, A, \neg \rangle \) of \( P_{fly}: \)
Translated ABA framework

\[ P_{fly}: \]
\[ fly \leftarrow bird, \text{not abnormalBird} \]
\[ abnormalBird \leftarrow bird, \text{wounded} \]
\[ \neg fly \leftarrow \text{wounded} \]
\[ \text{wounded} \leftarrow \]
\[ bird \leftarrow \]

Translated ABA framework \( \langle L, R, A, \neg \rangle \) of \( P_{fly} \):

- \( R = \{ fly \leftarrow bird, \text{not abnormalBird}; abnormalBird \leftarrow bird, \text{wounded}; \neg fly \leftarrow \text{wounded}; \text{wounded} \leftarrow; bird \leftarrow \} \)
Translated ABA framework

\( \mathcal{P}_{\text{fly}}: \)

\[
\begin{align*}
\text{fly} &\leftarrow \text{bird}, \text{not abnormalBird} \\
\text{abnormalBird} &\leftarrow \text{bird}, \text{wounded} \\
\neg \text{fly} &\leftarrow \text{wounded} \\
\text{wounded} &\leftarrow \\
\text{bird} &\leftarrow
\end{align*}
\]

Translated ABA framework \( \langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \neg \rangle \) of \( \mathcal{P}_{\text{fly}}: \)

- \( \mathcal{R} = \{ \text{fly} \leftarrow \text{bird}, \text{not abnormalBird}; \text{abnormalBird} \leftarrow \text{bird}, \text{wounded}; \neg \text{fly} \leftarrow \text{wounded}; \text{wounded} \leftarrow; \text{bird} \leftarrow \} \)

- \( \mathcal{A} = \{ \text{not abnormalBird} \} \)
Translated ABA framework

\[ P_{\text{fly}}: \]
\[ \text{fly} \leftarrow \text{bird, not abnormalBird} \]
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Translated ABA framework \( \langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \neg \rangle \) of \( P_{\text{fly}}: \)

- \( \mathcal{R} = \{ \text{fly} \leftarrow \text{bird, not abnormalBird}; \]
  \[ \text{abnormalBird} \leftarrow \text{bird, wounded}; \]
  \[ \neg \text{fly} \leftarrow \text{wounded}; \]
  \[ \text{wounded} \leftarrow; \text{bird} \leftarrow \} \]
- \( \mathcal{A} = \{ \text{not abnormalBird} \} \)
- \( \text{not abnormalBird} = \{ \text{abnormalBird} \} \)
Arguments

- $\mathcal{R} = \{ \text{fly} \leftarrow \text{bird, not abnormalBird}; \text{abnormalBird} \leftarrow \text{bird, wounded}; \, \neg \text{fly} \leftarrow \text{wounded}; \, \text{wounded} \leftarrow; \, \text{bird} \leftarrow \}$
- $A = \{ \text{not abnormalBird} \}$
- not abnormalBird = \{ abnormalBird \}
Arguments

\[ \mathcal{R} = \{ fly \leftarrow bird, \text{not abnormalBird}; \]
\[ \quad \text{abnormalBird} \leftarrow bird, \text{wounded}; \]
\[ \quad \neg fly \leftarrow \text{wounded}; \text{wounded} \leftarrow; \text{bird} \leftarrow \} \]

\[ \mathcal{A} = \{ \text{not abnormalBird} \} \]

\[
\text{not abnormalBird} = \{ \text{abnormalBird} \}
\]
Arguments

- $R = \{ \text{fly } \leftarrow \text{bird, not abnormalBird};$
  
  $\text{abnormalBird } \leftarrow \text{bird, wounded};$

  $\neg \text{fly } \leftarrow \text{wounded}; \text{wounded } \leftarrow; \text{bird } \leftarrow \}$

- $A = \{\text{not abnormalBird}\}$

- \text{not abnormalBird} = \{\text{abnormalBird}\}$

Arguments: label : $(\text{Assumptions, Facts}) \vdash \text{conclusion}$

$A_1 : (\{\text{not abnormalBird}\}, \emptyset) \vdash \text{not abnormalBird}$
Arguments

- $\mathcal{R} = \{ \text{fly} \leftarrow \text{bird}, \text{not abnormalBird}; \text{abnormalBird} \leftarrow \text{bird}, \text{wounded}; \neg \text{fly} \leftarrow \text{wounded}; \text{wounded} \leftarrow; \text{bird} \leftarrow \}$
- $\mathcal{A} = \{ \text{not abnormalBird} \}$
- $\text{not abnormalBird} = \{ \text{abnormalBird} \}$

Arguments: $\text{label : (Assumptions, Facts)} \vdash \text{conclusion}$

- $A_1 : (\{ \text{not abnormalBird} \}, \emptyset) \vdash \text{not abnormalBird}$
- $A_2 : (\emptyset, \{ \text{bird} \}) \vdash \text{bird}$
- $A_3 : (\emptyset, \{ \text{wounded} \}) \vdash \text{wounded}$
Arguments

\[ R = \{ \text{fly} \leftarrow \text{bird}, \text{not abnormalBird}; \]
\[ \text{abnormalBird} \leftarrow \text{bird}, \text{wounded}; \]
\[ \neg \text{fly} \leftarrow \text{wounded}; \text{wounded} \leftarrow; \text{bird} \leftarrow \} \]

\[ A = \{ \text{not abnormalBird} \} \]

\[ \text{not abnormalBird} = \{ \text{abnormalBird} \} \]

Arguments: \textit{label} : (Assumptions, Facts) \vdash \textit{conclusion}

- \( A_1 : (\{ \text{not abnormalBird} \}, \emptyset) \vdash \text{not abnormalBird} \)
- \( A_2 : (\emptyset, \{ \text{bird} \}) \vdash \text{bird} \)
- \( A_3 : (\emptyset, \{ \text{wounded} \}) \vdash \text{wounded} \)
- \( A_4 : (\emptyset, \{ \text{wounded} \}) \vdash \neg \text{fly} \)
- \( A_5 : (\emptyset, \{ \text{bird}, \text{wounded} \}) \vdash \text{abnormalBird} \)
- \( A_6 : (\{ \text{not abnormalBird} \}, \{ \text{bird} \}) \vdash \text{fly} \)
Attacks

\[ A_1 : (\{not\ abnormalBird\}, \emptyset) \vdash not\ abnormalBird \]
\[ A_2 : (\emptyset, \{bird\}) \vdash bird \]
\[ A_3 : (\emptyset, \{wounded\}) \vdash wounded \]
\[ A_4 : (\emptyset, \{wounded\}) \vdash \neg\ fly \]
\[ A_5 : (\emptyset, \{bird, wounded\}) \vdash abnormalBird \]
\[ A_6 : (\{not\ abnormalBird\}, \{bird\}) \vdash fly \]
Attacks

\[ A_1 : (\{ \text{not normalBird} \}, \emptyset) \vdash \text{not normalBird} \]
\[ A_2 : (\emptyset, \{ \text{bird} \}) \vdash \text{bird} \]
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\[ A_4 : (\emptyset, \{ \text{wounded} \}) \vdash \neg \text{fly} \]
\[ A_5 : (\emptyset, \{ \text{bird, wounded} \}) \vdash \text{abnormalBird} \]
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**conclusion of A is contrary of assumption used in B**
Attacks

\[ \begin{align*}
A_1 : (\{ \text{not abnormalBird} \}, \emptyset) & \models \text{not abnormalBird} \\
A_2 : (\emptyset, \{ \text{bird} \}) & \models \text{bird} \\
A_3 : (\emptyset, \{ \text{wounded} \}) & \models \text{wounded} \\
A_4 : (\emptyset, \{ \text{wounded} \}) & \models \neg \text{fly} \\
A_5 : (\emptyset, \{ \text{bird}, \text{wounded} \}) & \models \text{abnormalBird} \\
A_6 : (\{ \text{not abnormalBird} \}, \{ \text{bird} \}) & \models \text{fly}
\end{align*} \]

Conclusion of \( A \) is contrary of assumption used in \( B \)

- \( A_5 \) attacks \( A_1 \) and \( A_6 \)
Attacks

\[ A_1 : (\{ \text{not abnormalBird} \}, \emptyset) \vdash \text{not abnormalBird} \]
\[ A_2 : (\emptyset, \{ \text{bird} \}) \vdash \text{bird} \]
\[ A_3 : (\emptyset, \{ \text{wounded} \}) \vdash \text{wounded} \]
\[ A_4 : (\emptyset, \{ \text{wounded} \}) \vdash \lnot \text{fly} \]
\[ A_5 : (\emptyset, \{ \text{bird, wounded} \}) \vdash \text{abnormalBird} \]
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**conclusion of A is contrary of assumption used in B**

- \( A_5 \) attacks \( A_1 \) and \( A_6 \)
- stable extension: \( \{ A_2, A_3, A_4, A_5 \} \)
Attacks

$A_1 : (\{\text{not abnormalBird}\}, \emptyset) \models \text{not abnormalBird}$

$A_2 : (\emptyset, \{\text{bird}\}) \models \text{bird}$

$A_3 : (\emptyset, \{\text{wounded}\}) \models \text{wounded}$

$A_4 : (\emptyset, \{\text{wounded}\}) \models \neg \text{fly}$

$A_5 : (\emptyset, \{\text{bird, wounded}\}) \models \text{abnormalBird}$

$A_6 : (\{\text{not abnormalBird}\}, \{\text{bird}\}) \models \text{fly}$

The conclusion of $A$ is contrary to the assumption used in $B$.

- $A_5$ attacks $A_1$ and $A_6$
- Stable extension: $\{A_2, A_3, A_4, A_5\}$

Corresponds to answer set $\{\text{bird, wounded, } \neg \text{fly, abnormalBird}\}$
Attacks

\[
\begin{align*}
A_1 : (\{ not \text{ abnormalBird}\}, \emptyset) & \vdash not \text{ abnormalBird} \\
A_2 : (\emptyset, \{ bird\}) & \vdash bird \\
A_3 : (\emptyset, \{ wounded\}) & \vdash wounded \\
A_4 : (\emptyset, \{ wounded\}) & \vdash \neg fly \\
A_5 : (\emptyset, \{ bird, wounded\}) & \vdash abnormalBird \\
A_6 : (\{ not \text{ abnormalBird}\}, \{ bird\}) & \vdash fly
\end{align*}
\]

conclusion of \( A \) is contrary of assumption used in \( B \)

- \( A_5 \) attacks \( A_1 \) and \( A_6 \)
- stable extension: \( \{ A_2, A_3, A_4, A_5 \} \)

Corresponds to answer set \( \{ bird, wounded, \neg fly, abnormalBird\} \)

\( \Rightarrow \) every literal has a corresponding argument
Justification idea

Why is l in the answer set?
Justification idea

Why is \( l \) in the answer set?

- supporting literals and no conflicts with other literals
Justification idea

Why is \( l \) in the answer set?
- supporting literals and no conflicts with other literals
- supporting literals = assumptions/facts of corresponding argument of \( l \)
Justification idea

Why is \( l \) in the answer set?

- supporting literals and no conflicts with other literals
- supporting literals = assumptions/facts of corresponding argument of \( l \)
- conflicts = attacks on corresponding argument of \( l \)
Justification idea

Why is l in the answer set?

- supporting literals and no conflicts with other literals
- supporting literals = assumptions/facts of corresponding argument of l
- conflicts = attacks on corresponding argument of l

2-step justification approach for l:
Justification idea

Why is $l$ in the answer set?
- supporting literals and no conflicts with other literals
- supporting literals = assumptions/facts of corresponding argument of $l$
- conflicts = attacks on corresponding argument of $l$

2-step justification approach for $l$:
- tree of attacking arguments: root = corresponding argument of $l$
Justification idea

Why is \( l \) in the answer set?
- supporting literals and no conflicts with other literals
- supporting literals = assumptions/facts of corresponding argument of \( l \)
- conflicts = attacks on corresponding argument of \( l \)

2-step justification approach for \( l \):
- tree of attacking arguments: root = corresponding argument of \( l \)
- supporting assumptions/facts of arguments in attack tree
Attack tree

\[ A_1 : (\{\text{not abnormalBird}\}, \emptyset) \vdash \text{not abnormalBird} \]
\[ A_2 : (\emptyset, \{\text{bird}\}) \vdash \text{bird} \]
\[ A_3 : (\emptyset, \{\text{wounded}\}) \vdash \text{wounded} \]
\[ A_4 : (\emptyset, \{\text{wounded}\}) \vdash \neg \text{fly} \]
\[ A_5 : (\emptyset, \{\text{bird}, \text{wounded}\}) \vdash \text{abnormalBird} \]
\[ A_6 : (\{\text{not abnormalBird}\}, \{\text{bird}\}) \vdash \text{fly} \]

- \( A_5 \) attacks \( A_1 \) and \( A_6 \)
- stable extension: \( \{A_2, A_3, A_4, A_5\} \)
- answer set: \( \{\text{bird}, \text{wounded}, \neg \text{fly}, \text{abnormalBird}\} \)
**Attack tree**

\[ A_1 : (\{\text{not abnormalBird}\}, \emptyset) \vdash \text{not abnormalBird} \]
\[ A_2 : (\emptyset, \{\text{bird}\}) \vdash \text{bird} \]
\[ A_3 : (\emptyset, \{\text{wounded}\}) \vdash \text{wounded} \]
\[ A_4 : (\emptyset, \{\text{wounded}\}) \vdash \neg\text{fly} \]
\[ A_5 : (\emptyset, \{\text{bird, wounded}\}) \vdash \text{abnormalBird} \]
\[ A_6 : (\{\text{not abnormalBird}\}, \{\text{bird}\}) \vdash \text{fly} \]

- \( A_5 \) attacks \( A_1 \) and \( A_6 \)
- stable extension: \( \{A_2, A_3, A_4, A_5\} \)
- answer set: \( \{\text{bird, wounded, \neg fly, abnormalBird}\} \)

\[ A_6^- : (\{\text{not abnormalBird}\}, \{\text{bird}\}) \vdash \text{fly} \]
\[ A_5^+ : (\emptyset, \{\text{bird, wounded}\}) \vdash \text{abnormalBird} \]
Justification of answer set literals

\[ A_6^- : \{\text{not abnormalBird}\}, \{\text{bird}\} \models \text{fly} \]

\[ A_5^+ : (\emptyset, \{\text{bird}, \text{wounded}\}) \models \text{abnormalBird} \]

Justification of “fly”

\[ \text{just(fly)} = \]

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Justification of answer set literals

\[ A_6^- : (\{not \ abnormalBird\}, \{bird\}) \vdash fly \]

\[ A_5^+ : (\emptyset, \{bird, wounded\}) \vdash abnormalBird \]

**Justification of “fly”**

\[ just(fly) = \{ fly, \} \]
Justification of answer set literals

\[ A_6^N: \{\text{not abnormalBird}, \{\text{bird}\}\} \models \text{fly} \]

\[ A_5^+: (\emptyset, \{\text{bird, wounded}\}) \models \text{abnormalBird} \]

**Justification of “fly”**

\[
\text{just}(\text{fly}) = \\
\{ \{\text{fly}, \text{supp}_{rel}(\text{not abnormalBird, fly}), \text{supp}_{rel}(\text{bird, fly}), \ldots\} \}
\]
Justification of answer set literals

\[ A_6^\cdot : (\{\text{not abnormalBird}\}, \{\text{bird}\}) \models \text{fly} \]
\[ A_5^+ : (\emptyset, \{\text{bird, wounded}\}) \models \text{abnormalBird} \]

Justification of “fly”
\[
\text{just}(\text{fly}) = \\
\{ \{\text{fly}, \text{supp\_rel(} \text{not abnormalBird, fly})\}, \text{supp\_rel(} \text{bird, fly})\}, \\
\text{att\_rel(} \text{abnormalBird, not abnormalBird})\}
\]
Justification of answer set literals

\[ A_6^-(\{\text{not abnormalBird}\}, \{\text{bird}\}) \vdash \text{fly} \]

\[ A_5^+(\emptyset, \{\text{bird, wounded}\}) \vdash \text{abnormalBird} \]

Justification of “fly”

\[
\text{just(fly)} = \\
\{ \{ \text{fly, supp\_rel(not abnormalBird, fly), supp\_rel(bird, fly),}\}, \\
\text{att\_rel(abnormalBird, not abnormalBird),}\}, \\
\text{supp\_rel(bird, abnormalBird),}\}, \\
\text{supp\_rel(wounded, abnormalBird)} \} \} 
\]
Justification of answer set literals

\[ just(fly) = \{\{ fly, supp\_rel(not\ abnormalBird, fly), supp\_rel(bird, fly),
\text{att\_rel(abnormalBird, not\ abnormalBird),}
\text{supp\_rel(bird, abnormalBird),}
\text{supp\_rel(wounded, abnormalBird)}\}\} \]
Justification of answer set literals

\[
just(fly) = \\
\{ \{ fly, \text{supp}_\text{rel}(\text{not abnormalBird, fly}), \text{supp}_\text{rel}(\text{bird, fly}), \text{att}_\text{rel}(\text{abnormalBird, not abnormalBird}), \text{supp}_\text{rel}(\text{bird, abnormalBird}), \text{supp}_\text{rel}(\text{wounded, abnormalBird}) \} \}
\]
ABA-Based Answer Set Justification:

Future work:
- justification for answer set programs with preferences
- possible applications: law, medicine
ABA-Based Answer Set Justification:

- translate answer set program into ABA framework

Summary & Future Work

ABA-Based Answer Set Justification:

- translate answer set program into ABA framework
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- translate answer set program into ABA framework
- correspondence between AS and stable extension

Future work:
- justification for answer set programs with preferences
- possible applications: law, medicine
Summary & Future Work

ABA-Based Answer Set Justification:

- translate answer set program into ABA framework
- correspondence between AS and stable extension
- use attack tree of corresponding argument to justify a literal

Future work:
- justification for answer set programs with preferences
- possible applications: law, medicine
ABA-Based Answer Set Justification:
- translate answer set program into ABA framework
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Future work:
- justification for answer set programs with preferences
- possible applications: law, medicine
Thank you for your attention!